1.—The geology of southwestern Australia—a review

By M. H. Johnstone[1], D. C. Lowry[1] and P. G. Quilty[1]

Abstract

The gneisses and granites which constitute the bulk of the Archaean Yilgarn Block give a surprisingly consistent age of 2,667 ± 27 m.y. However, metasedimentary belts infolded into this gneissic terrain contain boulders dated at 3,000 m.y., so the younger figure probably represents the time of stabilization of the radiogenic elements of the shield. Flanking the shield are belts of Proterozoic metamorphics which have been dated from 1300 m.y. to 670 m.y.

The first important Phanerozoic sedimentation consists of Early Permian glacially-derived rocks deposited in downwarps to the east and west of the main shield. The western trough continued to receive marine and lacustrine sediments throughout the Early Permian. In the southern Perth Basin, graben development began in the Late Permian with deposition of thick Upper Permian Coal Measures and coarse fluvial Triassic sandstone. In the north, the Upper Permian is represented by paralic to continental sandstone and the Lower Triassic by marine shale. In this northern area coarse sandstone marking the onset of graben tectonics does not appear until the Late Triassic. This tectonism and depositional style was renewed in the Late Jurassic to Early Neocomian after a period of comparative stability in the Middle Jurassic. The second tectonic phase also saw the development of a graben across the southern margin of Australia which again was filled with coarse detritus. Both of these graben were filled with detritus from the shield by an extensive river system whose relics are the chains of salt lakes seen today. In the Late Neocomian, spreading between India and Antarctica commenced and India moved away from Western Australia along the Wallaby-Perth transform. Marine shelf sedimentation then commenced on the west coast and spread into the southern graben in the Aptian when a widespread transgression occurred in the Eucla and Officer Basins. In Eocene times, the spreading between Australia and Antarctica commenced and, for the first time, warm waters from the Indian Ocean could enter the southern basins. Sedimentation in the Paleocene, Eocene and Miocene was largely carbonate but minor terrigenous material derived from the shield was deposited in the Perth Basin in the Paleocene-Early Eocene and near Albany in the Late Eocene.

Introduction

This paper is an abbreviated geological history of the southwestern portion of Australia. It highlights those phases of geological evolution which have helped to shape the landforms, soils, and the varied environments for the development of its present day unique flora and fauna.

Such a paper cannot be both all-embracing and at the same time, definitive. The later facets of the geological history of the southwestern corner of the continent which led to the isolation of this area and the development of its biological uniqueness are stressed to the detriment of the equally interesting history of the buildup of the Archaean nucleus which forms the core of the Australian continent. The latter has been well covered in Special Publication No. 3 of the Geological Society of Australia (1971.)

A pioneer study of the Perth basin was made by Campbell (1910), who examined its northern part and made two major contributions in recognising the existence of a major fault (the Darling Fault) and also in inferring a glacial origin for the Early Permian sediments. Jutson (1934) produced a monumental work on Western Australian geomorphology and discussed in some detail the salt lake system. McWhae *et al.*, (1958) produced a review of Western Australian stratigraphy and this work is still the standard reference for the Phanerozoic.

Tectonic elements

The Archaean Yilgarn Block (Fig. 1) is the major nucleus of the present Australian continent, but is one of many such nuclei of the Gondwanaland supercontinent (Fig. 2A). The dominant trend of gneissic foliation and orientation of infolded metasediments in the block is north-northwest.

Along the southern margin of the block, metamorphics of the Fraser Range and Albany-Esperance Blocks trend northeast-southwest and east-west respectively, almost at right angles to the grain of the abruptly truncated shield.

The variation of mineral association and metamorphic grade in a westerly direction in the Albany-Esperance Block is matched exactly by similar east-west trending rocks in the vicinity of the Windmill Islands in Eastern Antarctica (Oliver, 1972), providing one of the strongest pieces of evidence for the geological fit of Antarctica and Australia in the reconstruction of Gondwanaland.

Along the western margin of the Yilgarn Block, the Archaean Shield is separated from Proterozoic high grade metamorphic rocks (garnet granulites with a meridional trend) by the Darling Fault—a major crustal feature 1000 km long, trending north-south and having up to 15000 m of vertical movement since the Permian and with a history since at least the Proterozoic. To the north, the strike of the Proterozoic rocks becomes more northeast-southwest and they trend around the northern margin of the Yilgarn Block. Overlying the Archaean on the western margin of the block are several sequences of unmetamorphosed sediments which dip west into the present day Perth Basin (Billeranga and Moora Groups, Cardup Group). The Billeranga and Moora Groups (Fig. 1) may be unmetamorphosed margin facies which are age equivalents of the garnet granulites in the trough farther west.

[1]West Australian Petroleum Pty. Limited, G.P.O. Box C1580, Perth 6001.

During the Phanerozoic, the Precambrian crystalline shield acted as a stable emergent craton and sedimentation was restricted to marginal downwarps. Along the western margin of the shield a downwarp developed early in the Palaeozoic and was reactivated in the Permo-Carboniferous. Between the Late Triassic and the Early Cretaceous (Neocomian) a deep graben developed in the centre of this downwarp to accommodate the 15,000+ m of mainly continental sediments of the Perth Basin. Although the north-south Darling Fault forms the eastern

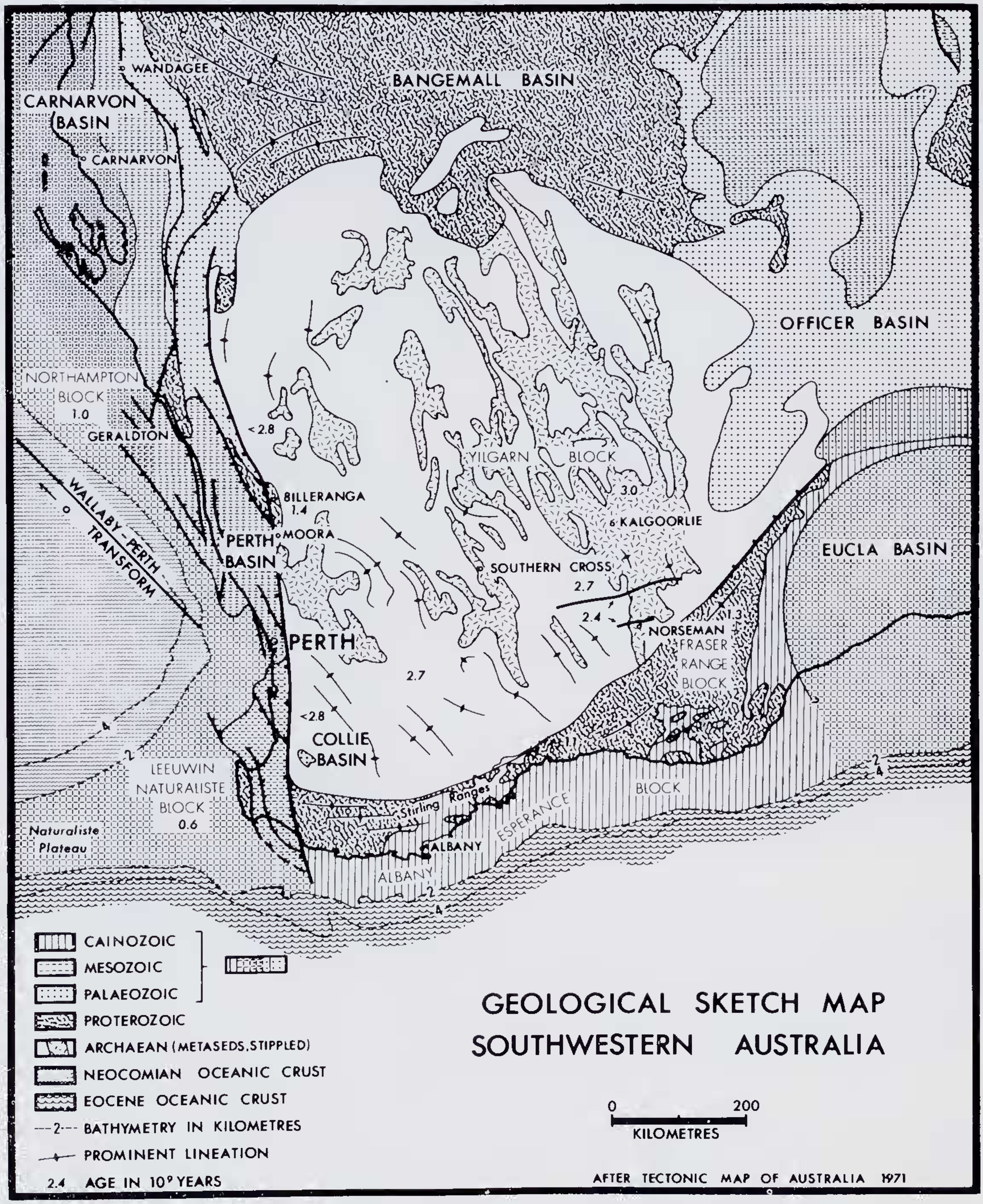

Figure 1.—Geological sketch map of southwestern Australia.

boundary between this graben and the shield (Jones and Pearson, 1972,), an equally prominent fault alignment in the graben is NNW, paralleling the grain of the Archaean Shield and that of a prominent transform fault in the Indian Ocean postulated by Falvey (1972).

Along the southern margin of the shield, a graben paralleling the lineation of the Albany-Esperance Block is inferred to have developed at least as early as the Late Jurassic but possibly even contemporaneously with the earlier Triassic formation of the Perth Basin. Little is known of the early history of this graben, since no remnant of it has yet been discovered off the southern coast of Western Australia, and much of its history is inferred from the Elliston Trough and the Robe-Penola Trough in South Australia. The whole of the western portion of this graben probably now lies on the Antarctic plate. A marginal marine Eocene sequence laps the southern coast and, probably, a thin veneer of Miocene limestones occurs offshore, overlying the crystalline basement beneath the southern shelf.

The eastern margin of the Yilgarn Block has never been downfaulted. Gentle epeirogenic warping formed the Eucla and Officer Basins where several relatively thin, flatlying sequences of sediments were deposited. In the latter, Ordovician, Permian, and Early Cretaceous sediments were laid down and the later Eucla Basin contains Cretaceous and Tertiary sequences.

The Precambrian crystalline shield and associated sediments

The dominant geological element in south-western Australia is the Archaean Yilgarn Block which forms the nucleus of the Western Australian Shield. This extends from near the south coast for 900 km to the north and has an east-west width of 700 km. Around this nucleus, belts of younger Precambrian rocks have accreted and its western margin is now marked by the deep Mesozoic graben of the Perth Basin. The eastern and southern margins of the shield have been onlapped by Cretaceous and Tertiary sediments.

Apart from the dissected western margin, the Yilgarn Block has an ancient, subdued land surface, and most of the older rocks are obscured by the widespread cover of laterite and its associated soil horizons which form extensive sandplains. The shield is composed mainly of gneisses and granites, with minor infolded belts of metasediments with a general north-northwest strike. These metasediments reveal different grades of regional metamorphism. The westernmost belt—the Jimperding belt (Prider, 1944), which has undergone the deepest dissection—consists of sillimanite-zone and kyanite-zone rocks. The other major belts, notably those of Southern Cross and Kalgoorlie, show degrees of metamorphic grade which lessen in an easterly direction (Fig. 1). The Jimperding and Southern Cross belts contain thin bedded, shallow water sediments whereas those of the Kalgoorlie region contain a thick eugeosynclinal sequence containing pillow basalts. The sedimentary and volcanic rock suites and the chemical composition and areal distribution of the various volcanic and hypabyssal rocks of the Eastern Goldfields are similar to those of present day island arcs and subduction zones. Possibly these Archaean greenstone belts represent the earliest zones of thick sedimentation when the "continental" crust was little more than a basaltic differentiate from the mantle (White *et al.*, 1971).

The original crust on which these ancient sediments were laid down has not yet been positively identified or dated radiometrically. The belts of metasediments are folded into the gneissic complex of the shield which probably represents a granitization of some of the earlier crustal differentiate. Alternatively, the greenstone belts became closed to the loss of radiogenic daughter elements earlier than the gneissic terrain of the catazonal basement rocks. Thus the geologically older gneisses may give younger radiometric ages (Windley and Bridgwater, 1971). The age of granitization is remarkably uniform over the Yilgarn Block, giving a Rb/Sr age of 2,667 ± 27 m.y. Granitic boulders within conglomerates in the Kalgoorlie greenstone belt have given an age of 3,000 m.y. which is consistent with the above theory (Compston and Arriens, 1968). It is interesting to note that the age of a prominent metasomatic event in the Kalgoorlie area (2,670 ± 30 m.y.) agrees closely with the widespread age of the gneissic parts of the shield (Arriens, 1971).

A final major event in the history of the Archaean shield was the emplacement of large east-west trending basic dykes near Norseman, of which the Jimberlana Dyke is the best known (Campbell *et al.*, 1970; and McCall and Leishman, 1971). These, and the associated gold mineralization at Kalgoorlie, are dated at 2,400 ± 40 m.y. (Fig. 1).

To the southeast of the Yilgarn Block, and striking approximately at right angles to the north-northwest trend of the main shield is a zone of augen gneisses with associated amphibolites and granulites which were welded onto its southern margin approximately 1,300 m.y. These rocks appear to merge into the east-west trending gneisses, granites, and metasediments of the Albany-Esperance Block which are dated at 1,150 ± 40 m.y. (Compston and Arriens, 1968) and which form the entire southern boundary of the shield.

Movement on the Darling Fault formed the Perth Basin—a graben with as much as 15,000 m of Late Palaeozoic and Mesozoic sediments. The Precambrian high grade metamorphics which floor this graben are much younger than the adjacent shield. To the north of Geraldton, the outcropping garnet granulites of the Northampton Block (Fig. 1) have been dated at 1,040 ± 50 m.y. whereas similar rocks from the Leeuwin-Naturaliste Block in the southwestern corner of the State give an isochron dating of 670 ± 25 m.y. (Compston and Arriens, 1968). The age of the younger granulites is also registered in oveprinted micas and pegmatites along the western margin of the Yilgarn Block.

Also along the western margin of the Yilgarn Block, two sequences of relatively unaltered sediments rest unconformably on the Archaean.

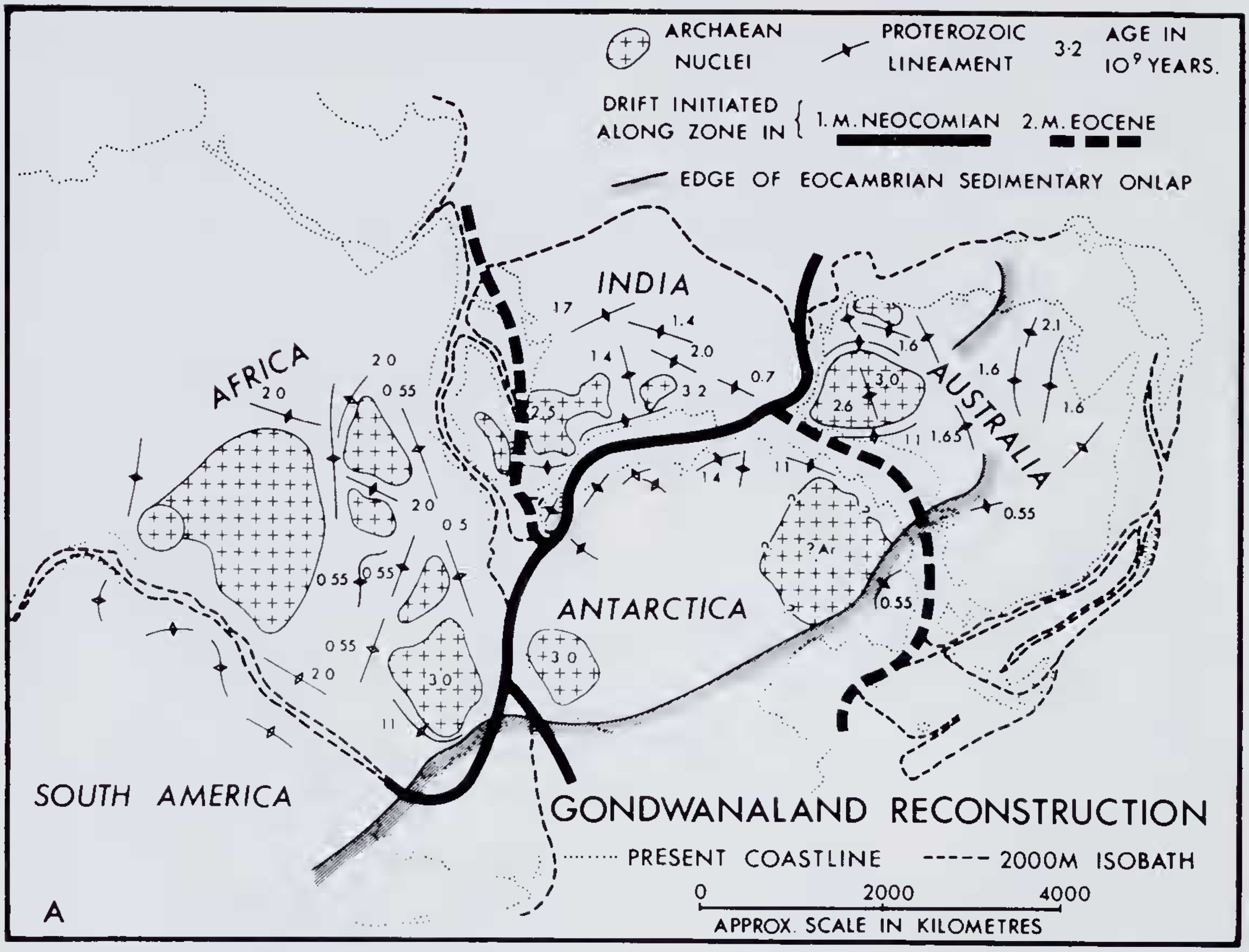

Figure 2A.—Reconstruction of the Gondwanaland continents (after several authors) showing major Precambrian cratonic elements and later Precambrian lineaments. Radiometric ages are shown in 10^9 years. Note that the prominent "Pan-African Event" of 0.55 x 10^9 years is primarily an overprint of a later tectonic event on earlier Proterozoic belts. The zones along which Gondwanaland broke in the Neocomian and in the Eocene are shown.

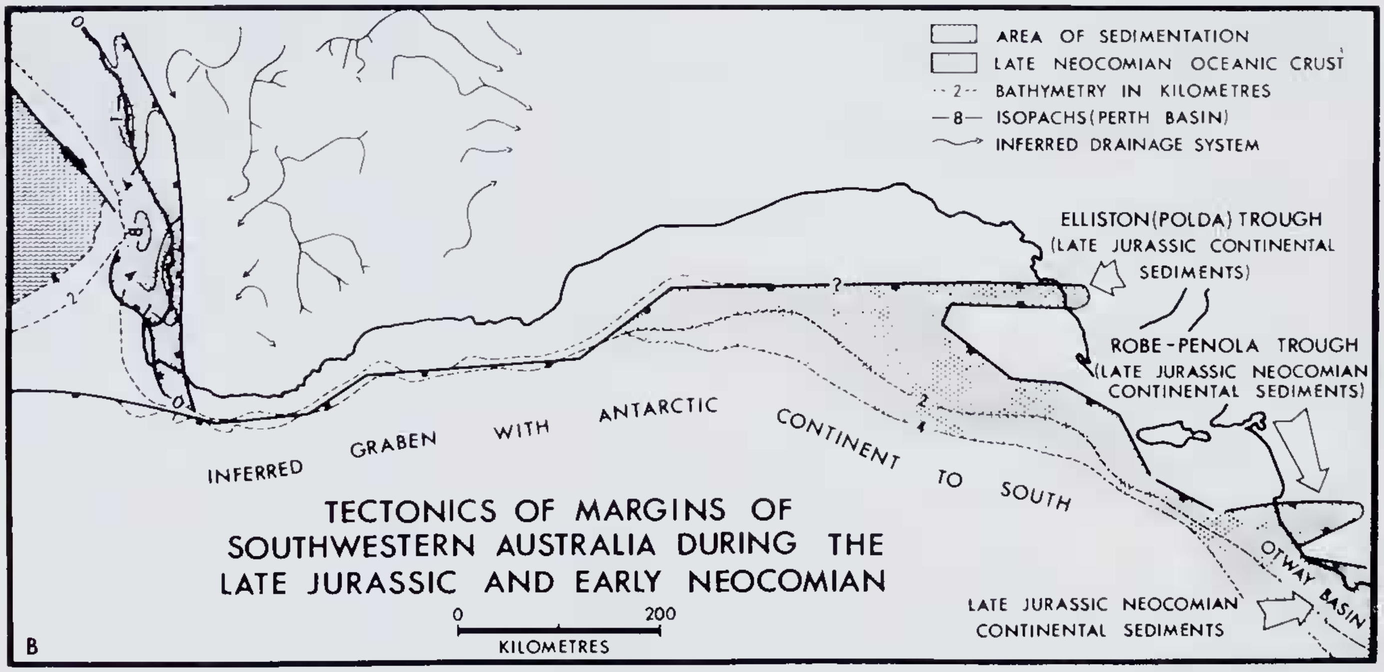

Figure 2B.—Late Jurassic to Neocomian sedimentation marginal to southwestern Australia and the inland drainage system.

In the vicinity of Perth, the Cardup Group can be dated as younger than the widespread pegmatite formation and dolerite intrusions of 700-750 m.y. (and probably no younger than 500-590 m.y.); and 350 km north of Perth, the Billeranga Group (Fig. 1) has been tentatively dated at 1,400 m.y. (Compston and Arriens, 1968).

In summary, it can be seen that the western and southern margins of the Archaean Yilgarn Block are marked by zones of Proterozoic high grade metamorphics, granites, and some unmetamorphosed sediments, the depositional and structural trends of which bear no relation to those of the Archaean nucleus. As can be demonstrated in other parts of Gondwanaland, these Proterozoic orogenic zones provide the lines of weakness along which the intitial graben formation ("rifting") and final drifting apart occurred (Fig. 2).

Older Palaeozoic

In the northern Perth Basin, more than 1050 m of cross bedded, fine to coarse fluviatile sandstones of probable Ordovician to Early Silurian age crop out (Konecki *et al.*, 1958). The Tumblagooda Sandstone may be a piedmont deposit associated with early movements on the northern portion of the Darling Fault for, although the entire sequence appears to be fluviatile or deposited in extremely shallow water, geophysical evidence indicates that the unit may be up to 3000 m thick.

In the Officer Basin during the Ordovician, very extensive basalt flows covered folded Proterozoic sediments. Subsequently in the Ordovician, Devonian or Carboniferous, there was widespread deposition of two fine grained sandstone units (Lennis Sandstone and Wanna Beds; see Lowry *et al.*, 1972). The units are interpreted as shallow marine sediments deposited under the influence of strong tidal currents in a sea that probably extended from the Canning Basin around the southern side of the Musgrave Block into South Australia.

Permo-Carboniferous

In the northern Perth Basin, the older Palaeozoic fluviatile deposits are overlain unconformably by a sequence of poorly bedded, poorly sorted, sandy siltstones containing abundant boulders (usually up to 50 cm in diameter, but exceptionally up to 6 m) of a great variety of Precambrian igneous, metamorphic, and sedimentary rocks. The variety of provenance, variety of size, and incompatability of these boulders with their fine-grained host sediment leads to their interpretation as icerafted detritus dropped into an epeiric sea from icebergs. Although no more than 130 m can be measured in any one section, it is thought that they may attain a total thickness of 350 m. Their age is Late Carboniferous to Early Permian (Sakmarian). Up to 2400 m of similar sediments were deposited in the Carnarvon Basin to the north, and similar, but thinner, deposits are known down the length of the Perth Basin and in the Collie, Canning, and Officer Basins, so the glaciation was widespread in Western Australia (Fig. 3). Sediments associated with this glaciation are known from Eastern Australia, and the other Gondwanaland continents, notably India, Africa and Antarctica.

In the northern Perth Basin, the glacial sequence is capped by 530 m of black marine shale (containing the Sakmarian goniatite *Metalegoceras jacksoni* Etheridge Jr.) which culminates in shellbanks rich in brachiopods, crinoids, and bryozoans. This, in turn, is capped by 330 m of fluviatile and coal swamp deposits, indicating an amelioration of the harsh, glacial climate. Three hundred metres of marine siltstone complete the sequence (Johnstone and Willmott, 1966). Mild faulting and erosion of this sequence preceded the deposition of a Late Permian sandstone which precedes thick (300-1000 m) Early Triassic marine shale.

Analysis of the structure and stratigraphy of the sequences indicates that, whereas the Early Permian glacial and later marine siltstones were linked with the sea by a gulf which connected with the Carnarvon Basin to the east of the Northampton Precambrian Block, the seas of the Late Permian and Early Triassic came into the basin from the west of the Northampton Block. Thus the minor faulting in the Late Permian of the Dongara area (Hosemann, 1971) actually dates the initiation of a set of north-northwest—south-southeast trending faults and rifts which produced the deep graben of the Perth Basin from Triassic to Neocomian times. This fault trend marks a crustal weakness which also controlled the inferred large transform fault which permitted India to move away from Western Australia during the Neocomian (Falvey, 1972).

The lower part of the Permian sequence (including minor glacial deposits at the base) is thin in the southern part of the Perth Basin, and in the Collie and Wilga Basins which were probably part of the same basin of deposition at the time. However, the accumulation of more than 2000 m of Late Permian coal measures in the southern Perth Basin suggests that rifting began in this area in the Late Permian. There is little evidence of marine conditions reaching this part of the basin during any part of the Permian.

There is no evidence of Permo-Carboniferous to Triassic sediments along the south coast. In the Officer Basin, the Paterson Formation and the Wilkinson Range Beds are thin (60-100 m), flat-lying, glacially derived, boulder-bearing sandstones of Early Permian age. These lie unconformably on the older Palaeozoic and are overlain disconformably by the Early Cretaceous Bejah Beds.

Triassic to Early Neocomian

In the northern Perth Basin, the quiet deposition of the Early Triassic marine shales and the Middle Triassic deltaic sediments in a gently subsiding trough was interrupted in the Late Triassic by intense uplift of the margins of the trough and the dumping in the rapidly subsiding graben of more than 2000 m of coarse grained fluvial sandstones (Jones and Pearson, 1972). In the southern Perth Basin, coarse dominantly fluviatile sandstone was deposited throughout the Triassic. Deposition continued

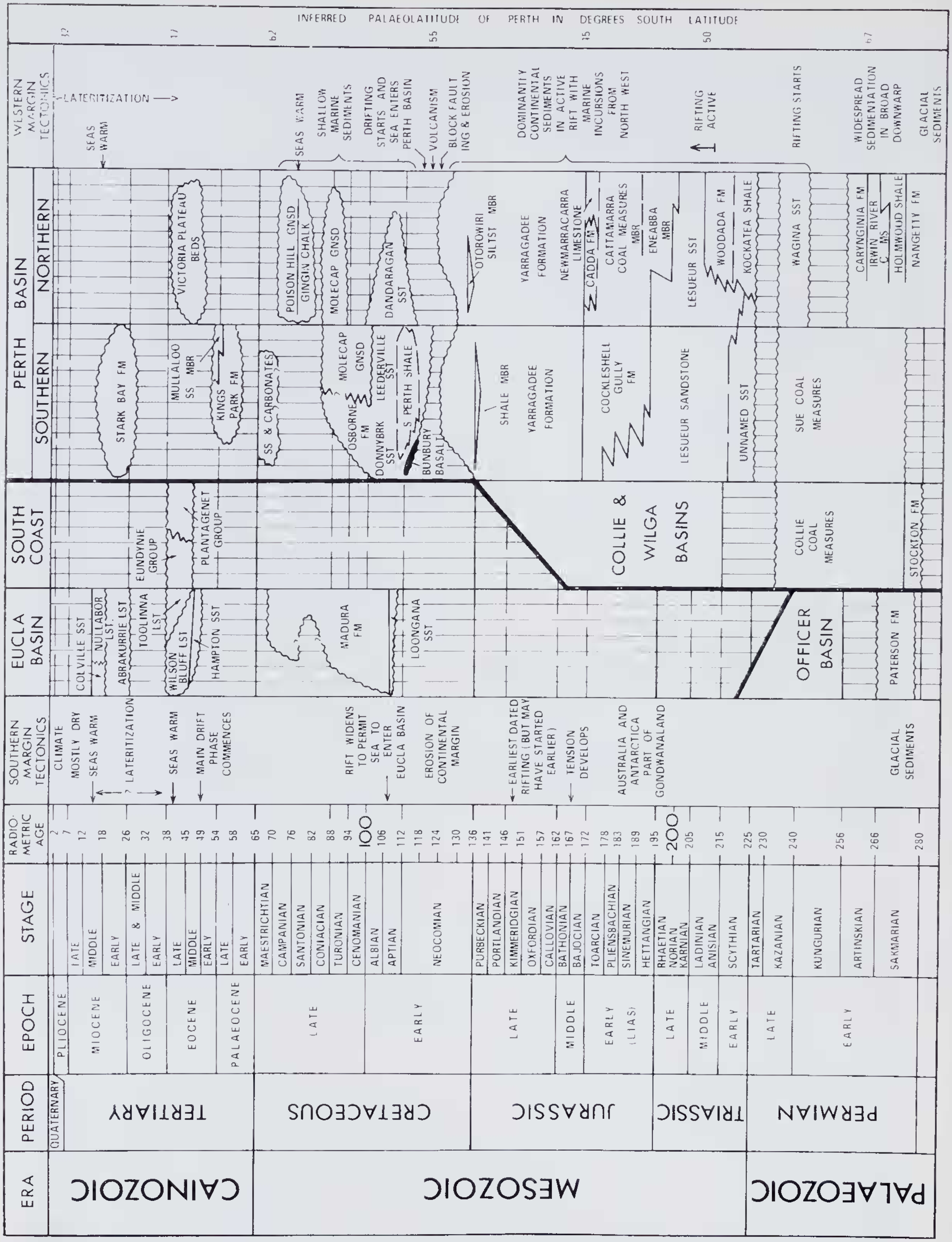

Figure 3.—Stratigraphic columns of the areas of sedimentation marginal to southwestern Australia.

uninterrupted into the Early Jurassic when up to 2400 m of sandstone and claystone grading upwards into coal swamp deposits were laid down. The climate of the Early Jurassic was thus favourable for the development of a dense coal swamp vegetation. In the Middle Jurassic, a minor marine incursion from the northwest deposited a widespread blanket about 250 m thick of shallow water marine shale, sandstone and limestone containing ammonites, pelecypods and gastropods of Bajocian age (Arkell and Playford, 1954).

Major movements of the trough and its borderlands in the Middle to Late Jurassic caused further deposition of the coarse fluvial sediments similar to those in the Triassic. Up to 4250 m of coarse sandstones were deposited during this major development of the Perth Basin rift.

In the Neocomian, the locus of intense down-faulting moved westwards into the offshore Vlaming Sub-basin where up to 6000 m of fluvial sand and estuarine shale and sand were deposited immediately before (and possibly during) the violent jostling of the fault blocks in the Perth Basin graben which preceded the active initiation of the transform fault which moved India away from the western coastal basins of Australia. The stage was then set for the next phase in the evolution of the west coast basins.

No sediments of Triassic to Neocomian age are known from the south coast area or the Eucla Basin. However, geophysical surveys and drilling in the Elliston (or Polda) Trough and the Duntroon Basin on the eastern side of the Eucla Basin, show that graben formation commenced in this area as early as Late Jurassic (Smith and Kamerling, 1969). This graben formation continued eastward into the Robe-Penola Trough in the Late Jurassic and had reached the eastern Otway, Bass, and Gippsland Basins by the Neocomian (Griffiths, 1971). These graben were the precursors of the spreading which separated Antarctica from Australia. Thus, although there is no published evidence for rocks of this age off the southern coast of Western Australia, it is logical to assume that the graben between southwestern Australia and Antarctica had formed by Late Jurassic times, and possibly even by Middle Jurassic or earlier.

Neocomian-Maestrichtian

Tectonism in the Perth Basin reached a climax in the Neocomian (Jones and Pearson, 1972). The sequence of events included major subsidence of the Vlaming Sub-basin (up to 6000 m); a period of arching and faulting causing local uplift and erosion of as much as 2500 m of the recently deposited soft sediments; eruption of the Bunbury Basalt at the southern end of the basin, and subsidence of the continental margin causing a marine transgression. These events mark the change from continental "rifting" to "drifting". With generation of sea floor between India and Australia the tectonic stresses were relieved, and the Darling Fault and most others ceased to move. Late subsidence within the graben was due to compaction of underlying sediments and general sagging of the continental margin. The precise mechanics of the split are still conjectural; however, it is likely that the Perth Basin is a rift controlled by an ancient crustal weakness that developed into a transform fault (Falvey, 1972).

Sediments deposited later in the Neocomian and Aptian include a thick marine shale west of Perth (South Perth Shale) and shallow marine and paralic glauconitic sandstone (Leederville Sandstone) (Fig. 4). Deposition at the southern end of the main Perth Basin was continental, but it presumably extended around the west side of the Leeuwin-Naturaliste Block, where marine sediments of this age have been recovered in deep sea cores (Burckle *et al.*, 1967).

The present salt lake system (Jutson, 1934), a relic of ancient drainage systems, is indicated on Figure 2B and has been discussed in several papers by Bettenay and Mulcahy (see their 1972 papers for full reference list).

The system seems to be a relic of the Late Jurassic-Early Cretaceous drainage, which was most active in filling the basins at that time, but which has had only a relatively minor sedimentational history since. Voluminous terrigenous sediments of Late Jurassic age (Perth Basin only) and Early Cretaceous (Perth and Eucla Basins) attest to well developed drainage systems to supply them. No sediments younger than Early Cretaceous seem voluminous enough to justify such a drainage system. Late Eocene sediments in Rollos Bore, Coolgardie (Balme and Churchill, 1959), show that the system is pre-Eocene. Although the present salt lake system is a relic of the most active (Late Jurassic to Neocomian) phase, it could also mark the drainage system which supplied sand to the Early Triassic.

In the Albian-Cenomanian and Senonian, thin greensands and a chalk bed were deposited north of Perth (Osborne Formation, Molecap Greensand, Gingin Chalk, and Poison Hill Greensand; see McWhae *et al.*, 1958). Maestrichtian sandstone and calcilutite occur offshore in Warnbro No. 1.

In the Eucla Basin, a marine transgression began in the Neocomian-Aptian (Ingram, 1968; more probably Aptian, A. Williams, *pers. comm.*). The beds of carbonaceous and glauconitic sandstone and shale (Madura Formation; see Lowry, 1970) lie on a deeply dissected granite surface in the southern portion of the basin, near the edge of the continental slope. The valleys, which are as much as 500 m deep, may have formed in the Late Jurassic and Neocomian by up-arching of the flank of a graben that developed along the impending Australia-Antarctica rupture. During the Aptian, much of the Australian continent was submerged and sea covered parts of the Canning, Officer, and Great Artesian Basins (Skwarko, 1967). In the central Eucla Basin, deposition of greensand continued, perhaps intermittently, into the Senonian.

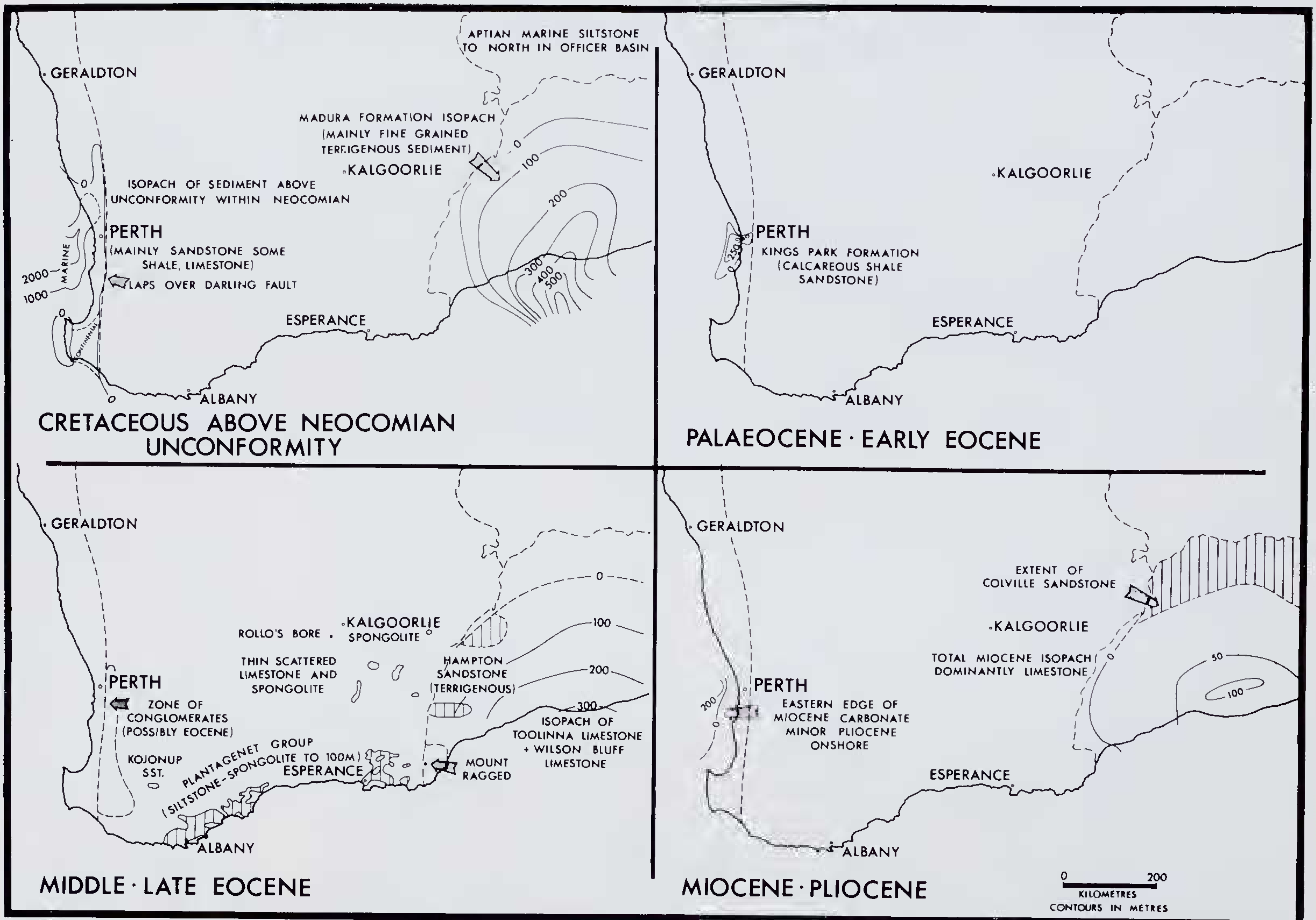

Figure 4.—Major cycles of deposition around southwestern Australia after the unconformity within the Neocomian.

The epeirogenic subsidence of the Eucla Basin is possibly part of a general subsidence of a newly developed southern continental margin following minor generation of sea floor between Antarctica and Australia. This interpretation is consistent with the palaeomagnetic data of Wellman *et al.*, (1969) and Weissel and Hayes' (1972) interpretation of sea floor magnetic anomalies. Although the latter interpretation is taken to indicate that the major motion of Australia away from Antarctica was initiated in the Eocene, stratigraphic evidence from the Eucla and Otway Basins indicates that a pronounced marine gulf extended across the southern part of the Continent during the Late Cretaceous. Thus Australia became an isolated continental mass by the uppermost Cretaceous, with only a tenuous link joining Tasmania to Antarctica across a transform fault.

Late Cretaceous faunas in the Gingin area and from the offshore Perth area contain abundant *Globotruncana* which Bandy (1967) would take to be an indication of warm water conditions. The presence of carbonate-rich sediments also supports this view. These warm water indicators are absent from the Eucla Basin but this absence could be due to facies control or water circulation rather than purely climate. It is unlikely that warm waters from the Indian Ocean would circulate freely into the narrow gulf separating Australia and Antarctica until at least the Middle Eocene when the southern tip of the Tasmanian peninsula had cleared Antarctica and thus permitted the warm Indian Ocean waters to flow through the widening gulf into the South Pacific Ocean. However, once the warm currents could penetrate the widening gulf, warm water forms from the Indian Ocean could migrate in an easterly direction along Australia's south coast. Hence the Eocene faunas of Australia's south coast should show marked similarities.

Rates of sedimentation and runoff had decreased markedly by this time and the drainage system probably became very subdued. This pattern of minimal influx of terrigenous material from the defunct river systems would have continued into the Tertiary.

Paleocene—Early Eocene

The only sediments of this age known are from the vicinity of Perth (Fig. 4) and have been documented by Quilty (*in press*). The maximum thickness of the Kings Park Formation near Perth is approximately 500 m of shale and sandstone with some carbonate content. The sediments can be differentiated into a northern sandy marine facies and a more southerly marine shale facies. The former may be related to the ancestral Swan River where it enters the Perth Basin near Walyunga National Park. The shale facies is likely to have been deposited by smaller streams (Canning and Helena Rivers) flowing into a deep embayment—probably an old submarine canyon eroded during the Late Cretaceous and/or Early Paleocene into Cretaceous terrigenous sediments.

The drainage at this time is very minor compared with the Early Cretaceous but probably it ran in the same stream channels.

Very little can be said of the climate at this time as foraminiferal faunas are almost cosmopolitan. *Globorotalia rex* Martin, *G. dolabrata* Jenkins and other keeled *Globorotaliae* may indicate warm water conditions (Bandy, 1964).

Middle and Late Eocene

Marine sediments of Middle and Late Eocene age occur in the Eucla Basin and along the south coast between Esperance and Albany (Cockbain, 1967, 1968, Lowry, 1970, Quilty, 1969)—see Figure 4.

In the Eucla Basin, both Middle and Late Eocene are present but the Plantagenet Group to the west is so far known to contain only Late Eocene faunas.

The Eucla Basin sediments (Hampton Sandstone, Wilson Bluff Limestone, Toolinna Limestone) consist of up to 300 m of biogenic carbonate sediments containing the warm water bivalve *Spondylus*. The thin sandstone at the base suggests minor terrigenous material being supplied by the poor drainage, probably from the northwest.

The Plantagenet Group consists of up to 100 m of fine sandstone, spongolite and minor limestone. Near Esperance, the limestone contains the large warm water foraminifer *Asterocyclina* and the tropical alga *Neomeris* (Cockbain, 1967, 1969).

Thus the Middle and Late Eocene sediments attest to warm water sedimentation and also the presence of minor southerly drainage.

Early and Middle Miocene

Sediments of Early and Middle Miocene age occur in both the Perth and Eucla Basins (Fig. 4).

In the Perth Basin, friable limestones with some dolomite and chert (Stark Bay Formation of Quilty, *in press*) occur offshore from Perth and attain a thickness of some 200-250 m. There is no terrigenous content. They contain abundant bryozoans and foraminifera including *Lepidocyclina* and keeled *Globorotalia*, both warm water indicators.

The age of the sediments is latest Early Miocene and earliest Middle Miocene.

Sedimentation in the Eucla Basin took place over a longer period, beginning before and ceasing after that in the Perth Basin. The age limits of the Eucla Basin Miocene are not as well established as those in the Perth Basin. The older Miocene sequence (Abrakurrie Limestone) secms to be Early Miocene (Longfordian of southeastern Australia) and underlies the Nullarbor Limestone and Colville Sandstone disconformably. The Nullarbor Limestone and Colville Sandstone are coeval and laterally equivalent. Both contain Middle Miocene warm water benthonic foraminifera which may indicate sediments slightly younger than the Middle Miocene of the Perth Basin. The Colville Sandstone occurs on the northern rim of the Eucla Basin and is probably derived from Palaeozoic sandstones by marine erosion.

Pliocene

Pliocene marine sediments occur in small, scattered, poorly-known lenses to the north, east and south of Perth. Darragh and Kendrick (1971) reported ages based on mollusc faunas and Kendrick (*pers. comm.*) has since substantiated a Pliocene age from Redcliffe (a Perth suburb) on the basis of the pelagic gastropod *Hartungia typica typica* Bronn.

The knowledge of the Pliocene is so far too imperfect to make any comments on palaeoecology.

Pleistocene—Recent

A wide variety of Quaternary units is developed around the coastal margin. On the west, the sediments of the central Perth Basin have been eroded to form a coastal plain with alluvium inland and a series of dune systems, lakes, interdunal swamps, and relict estuaries nearer the coast (McArthur and Bettenay, 1960). The calcareous dune sands show varying degrees of lithification and leaching, according to age. The lithified dune systems and intercalated marine lenses are known as the "Coastal Limestone". These form prominent hills along the coast and the backbone of several offshore islands and reefs. The total age range of the "Coastal Limestone" is unknown but the unit is still forming along the coast and probably on the seabed. The greatest known age is 100,000 ± 20,000 years for reef limestone on Rottnest Island (Teichert, 1967).

Palaeontological age control is very poor but Kendrick (*pers. comm.*) notes the presence of early Pleistocene marine molluscs at Jandakot. He also (Kendrick, 1960) has discussed the significance of a Late Pleistocene mollusc fauna in the "Coastal Limestone" at Peppermint Grove. Details of these various Quaternary rock and soil units are given in Dr. Seddon's excellent review of the Swan Coastal Plain (Seddon, 1972).

Similar dune systems occur along the south coast and, in the Eucla Basin, the Roe Calcarenite is tentatively referred to the Pleistocene. The formation is marine with a warm water fauna which may indicate an interglacial age for the unit if it is Pleistocene.

Other young sediments in the Eucla Basin include kankar and dune sands discussed in some detail by Lowry (1970).

Lateritization

Details of laterites in the southwest of Australia will be dealt with in a subsequent article in this volume, but some comments will be made here on stratigraphic evidence for the time of lateritization. In eastern arid areas the laterite is Miocene or Oligocene in age. The evidence is that the Late Eocene Eundynie Group around Norseman, the Plantagenet Group around Esperance and the Early Cretaceous Bejah Formation of the Officer Basin are all lateritized whereas the adjoining Middle Miocene Colville Sandstone of the Eucla Basin is not.

In the extreme southwest, Pleistocene alluvium and dune sands have been lateritized and laterite appears to be forming at the present day on the coastal plain where there is a temperate climate with a strongly seasonal rainfall of 750 to 1000 mm.

In coastal areas north of Perth, Late Cretaceous sediments are lateritized but there are no datings to indicate a minimum age. However, the laterite is considerably dissected, and a Tertiary age is likely. Farther north, in the Carnarvon Basin, lateritization has affected rocks of Late Eocene and older age but not Middle Miocene and younger.

Thus there was a major period of lateritization in the Oligocene and/or Miocene. Earlier periods have been assumed by other workers, but there is no geological evidence for them. Since the Middle Miocene, lateritization has occurred (presumably intermittently) only in coastal areas of the southwest that have a moderate and strongly seasonal rainfall.

Crustal movements in the Cainozoic

Whereas the Eocene sediments along the south coast of Western Australia accumulated in very shallow water and are now only a few metres above their level of deposition, the old beach levels associated with this cycle of sedimentation are now at about 300 m at Mt Ragged (Lowry, 1970) and the Stirling Range (H. Schumann, *pers. comm.*). Also, marine sediments of Eocene age now at 300 m at Lake Cowan near Norseman, and in the Kennedy Range in the Carnarvon Basin, near the northern margin of the Yilgarn Block. Thus it appears that the whole shield area (apart from the present coastal margins) has been uplifted by approximately 300 m since the Eocene, but the relative importance of marginal warping and eustatic sea level changes cannot be determined.

Perhaps the most perplexing structural unit near the south coast of Western Australia is the Stirling Range. This feature, which lies just south of the southern margin of the Archaean Shield, thrusts metasediments of the Albany-Esperance Block to a height of 1200 m above sea level (about 1000 m above the level of the flat shield to the north). The abruptness and straightness of the north front of the range suggest that this is a very young feature, but the presence of the Late Eocene marine bench at 300 m and the concordance of this with other Eocene levels indicates that the Stirling Range was in existence prior to the Late Eocene. Perhaps its elevation was a final adjustment of the contental margin before block faulting ceased with Eocene drift.

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